

Multi-messenger emissions by magnetar remnants of binary neutron star mergers

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Plan

Part 1: Magnetars

Part 2: Dynamics

Part 3: Neutrino signatures

Part 4: EM signatures and prospects

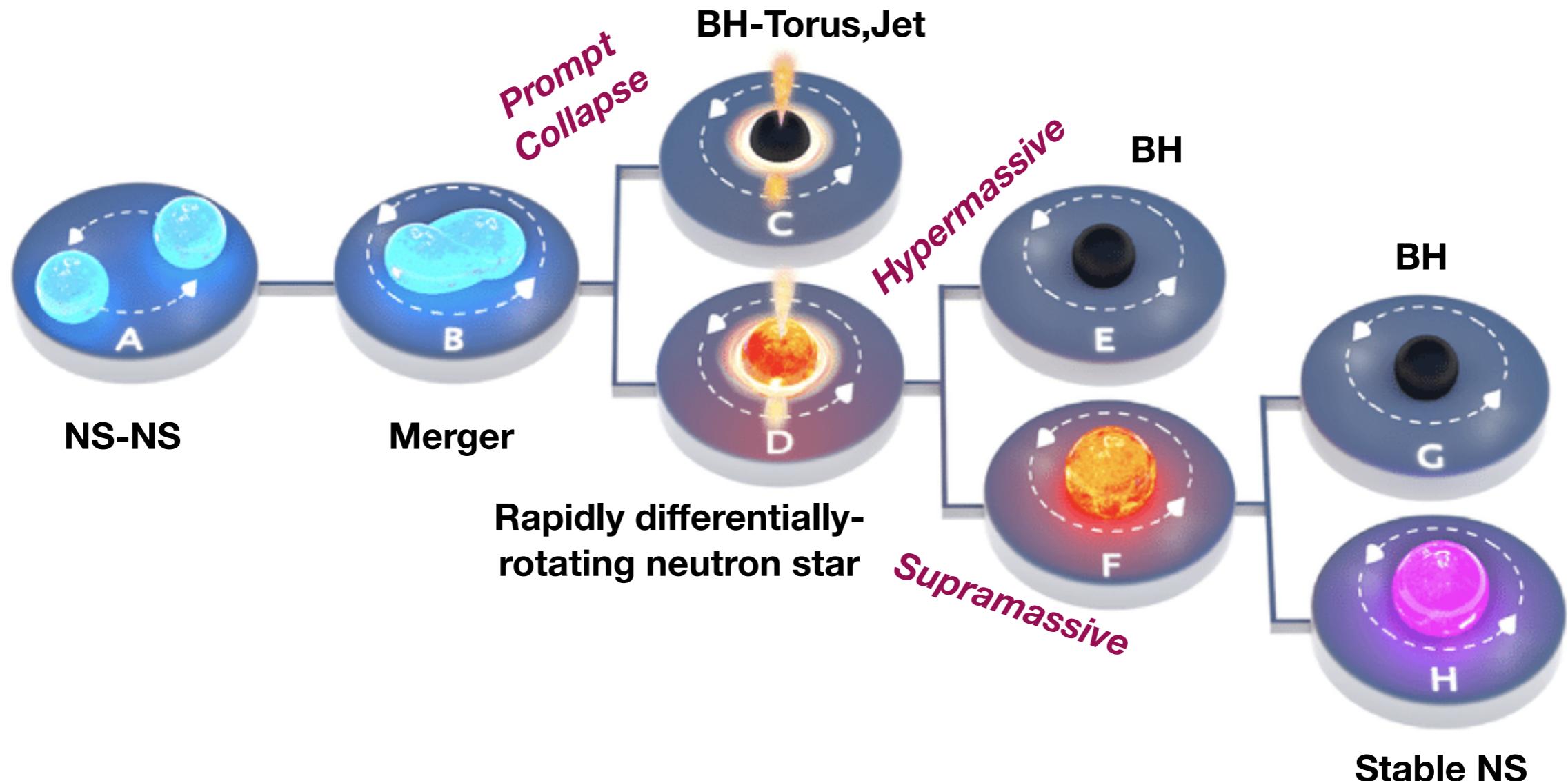
Based on

Multi-messenger emissions by magnetar remnants of binary neutron star mergers

MM, Shigeo. S. Kimura

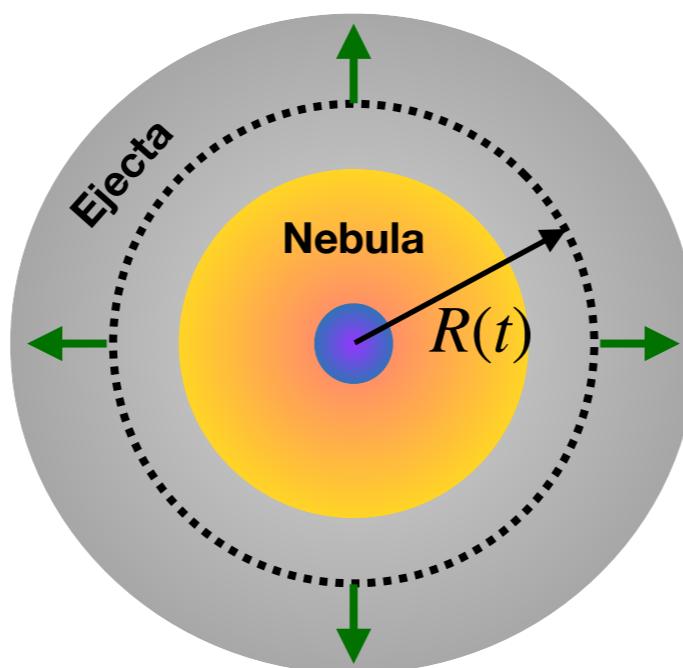
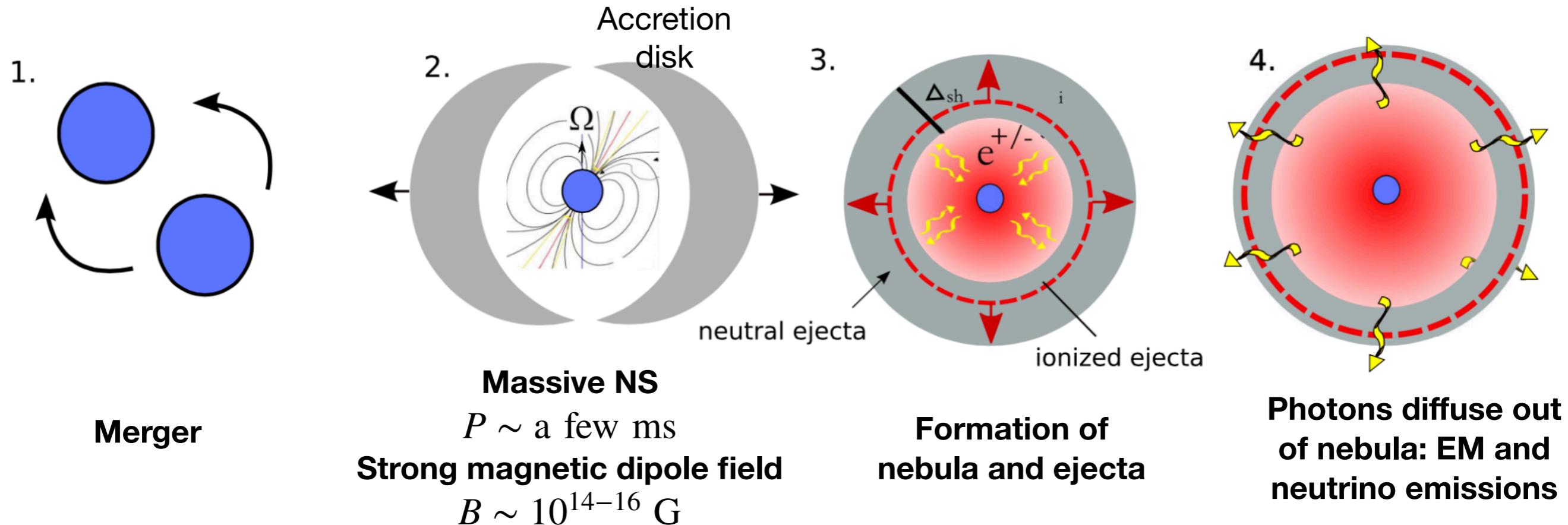
In preparation

Fate of NS-NS mergers: Magnetars



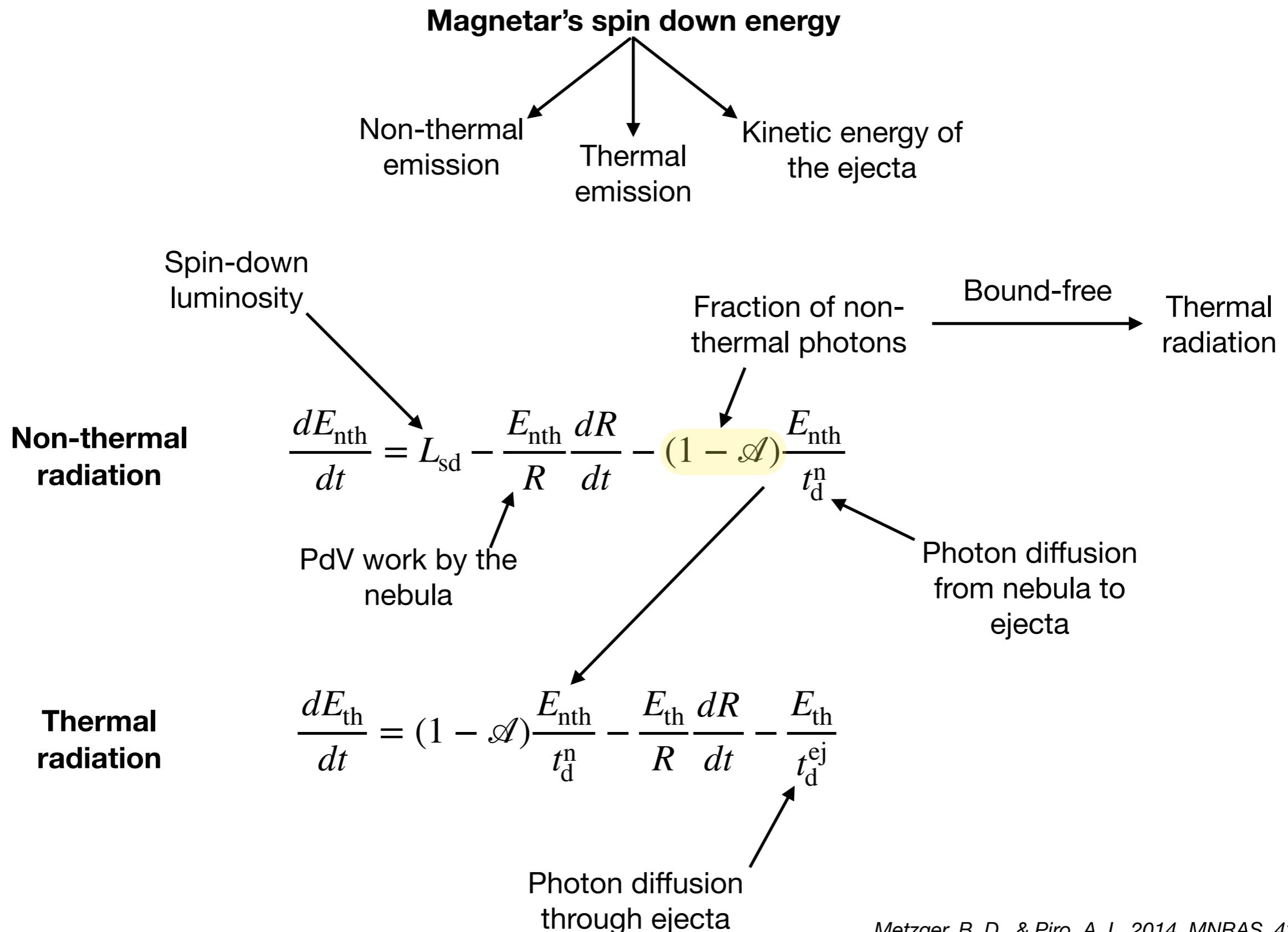
Fate decided by EOS, Mass, Spin,

Physical Model: Magnetars

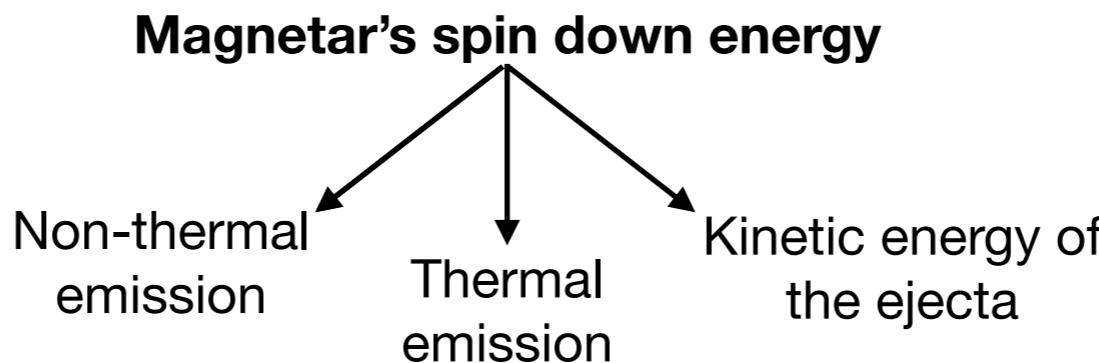


Metzger, B. D., & Piro, A. L. 2014, MNRAS, 439, 3916
Metzger, B. D., Vurm, I., Hascoët, R., & Beloborodov, A. M. 2014, MNRAS, 437, 703

Physical Model



Physical Model



Non-thermal radiation

$$\frac{dE_{\text{nth}}}{dt} = L_{\text{sd}} - \frac{E_{\text{nth}}}{R} \frac{dR}{dt} - (1 - \mathcal{A}) \frac{E_{\text{nth}}}{t_d^n}$$

Thermal radiation

$$\frac{dE_{\text{th}}}{dt} = (1 - \mathcal{A}) \frac{E_{\text{nth}}}{t_d^n} - \frac{E_{\text{th}}}{R} \frac{dR}{dt} - \frac{E_{\text{th}}}{t_d^{\text{ej}}}$$

Mean ejecta velocity

$$M_{\text{ej}} v \frac{dv}{dt} = \frac{1}{R} (E_{\text{nth}} + E_{\text{th}}) \frac{dR}{dt}$$

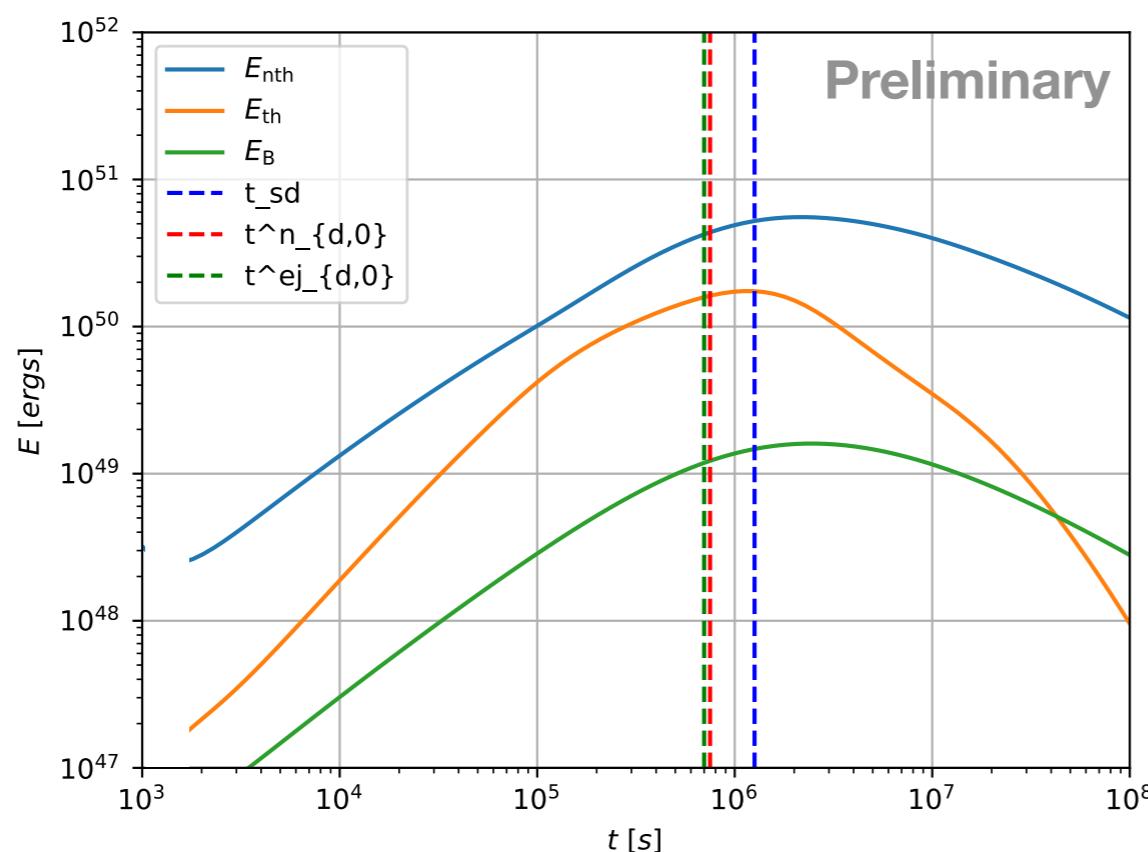
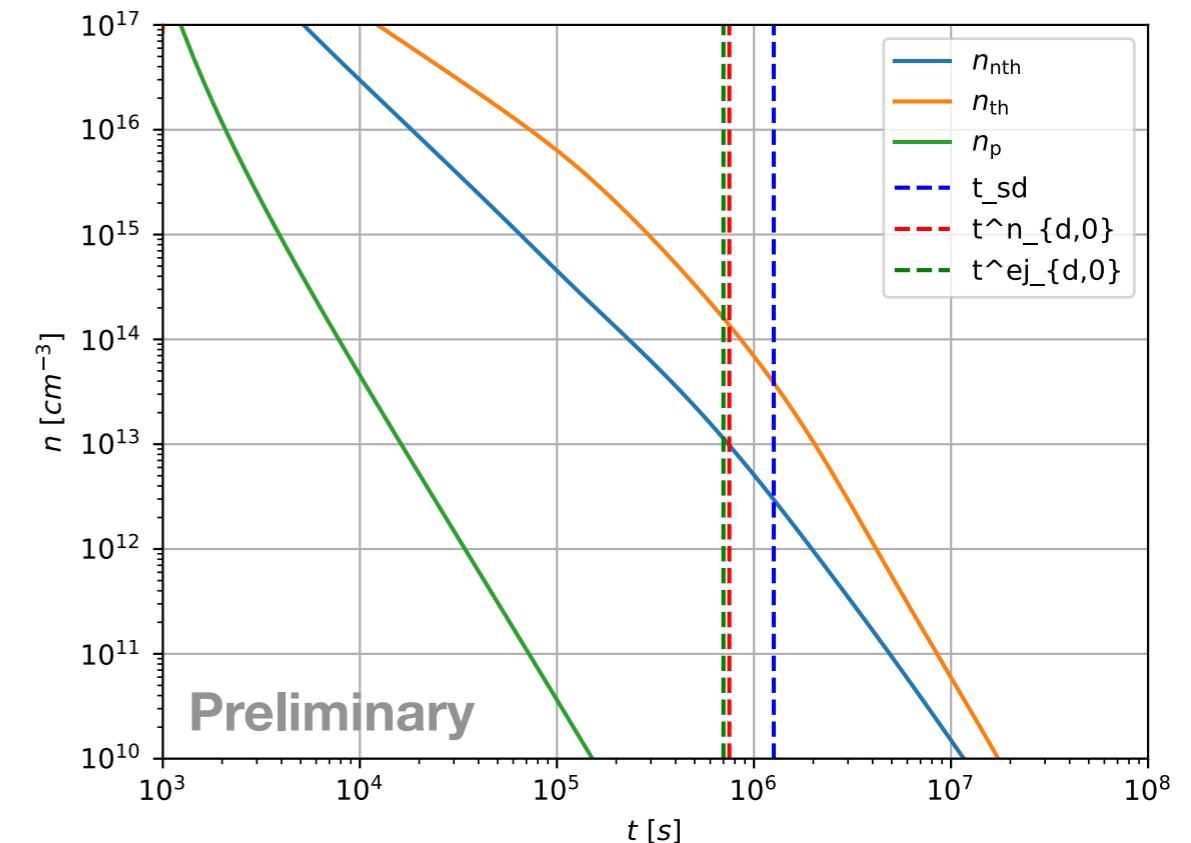
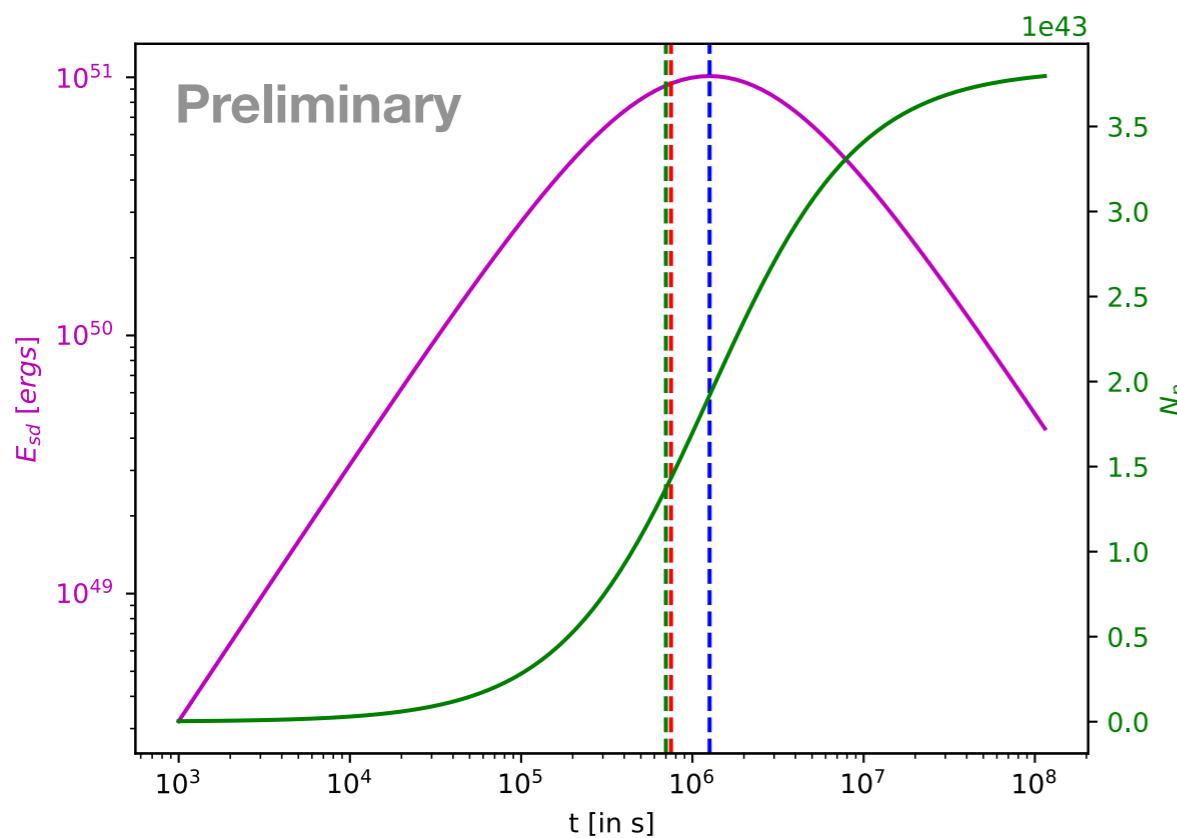
Magnetic energy of nebula

(Nebula: Strong magnetization)

$$\frac{dE_B}{dt} = \epsilon_B L_{\text{sd}} - \frac{E_B}{R} \frac{dR}{dt}$$

$\epsilon_B \sim 10^{-2}$

Physical Model



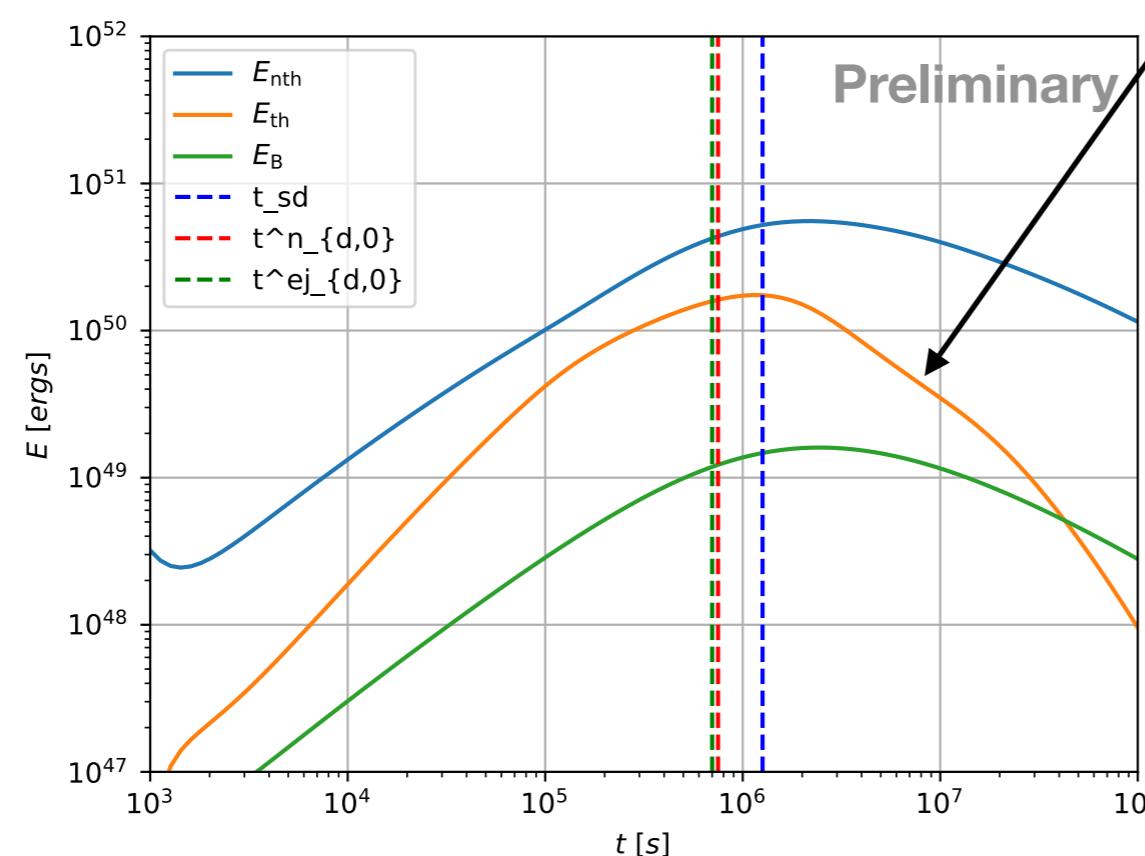
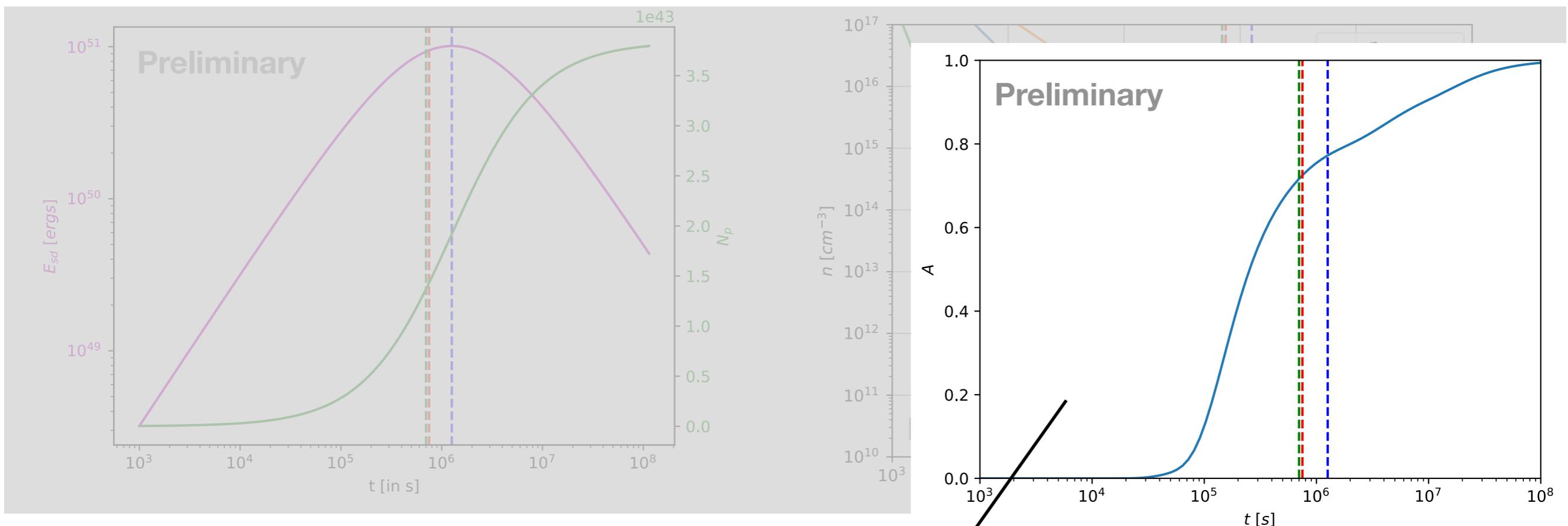
$$M_{ej} = 0.03 M_{\text{sun}}$$

$$P = 3 \text{ ms}$$

$$B_0 = 10^{14} \text{ G}$$

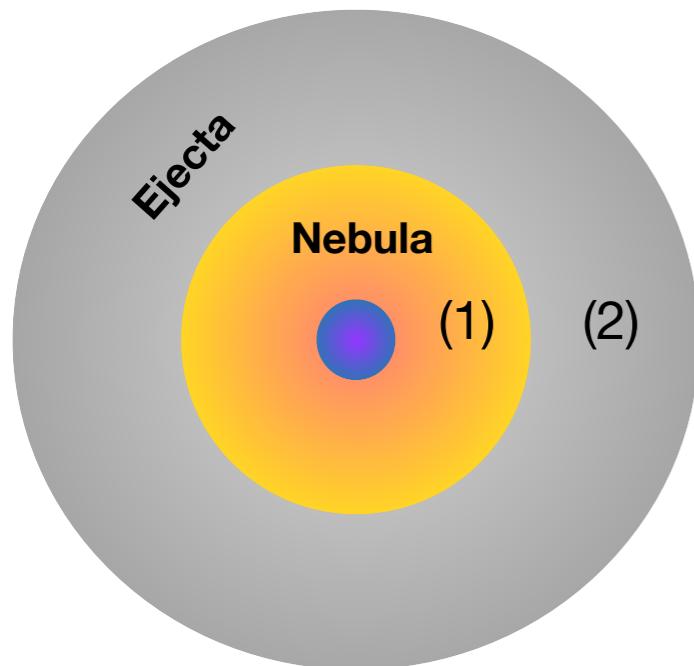
$$v_0 = 0.2c$$

Physical Model



Details in a few slides

Neutrino production



Ions from NS surface accelerated due to the surface magnetic field

Cooling processes →

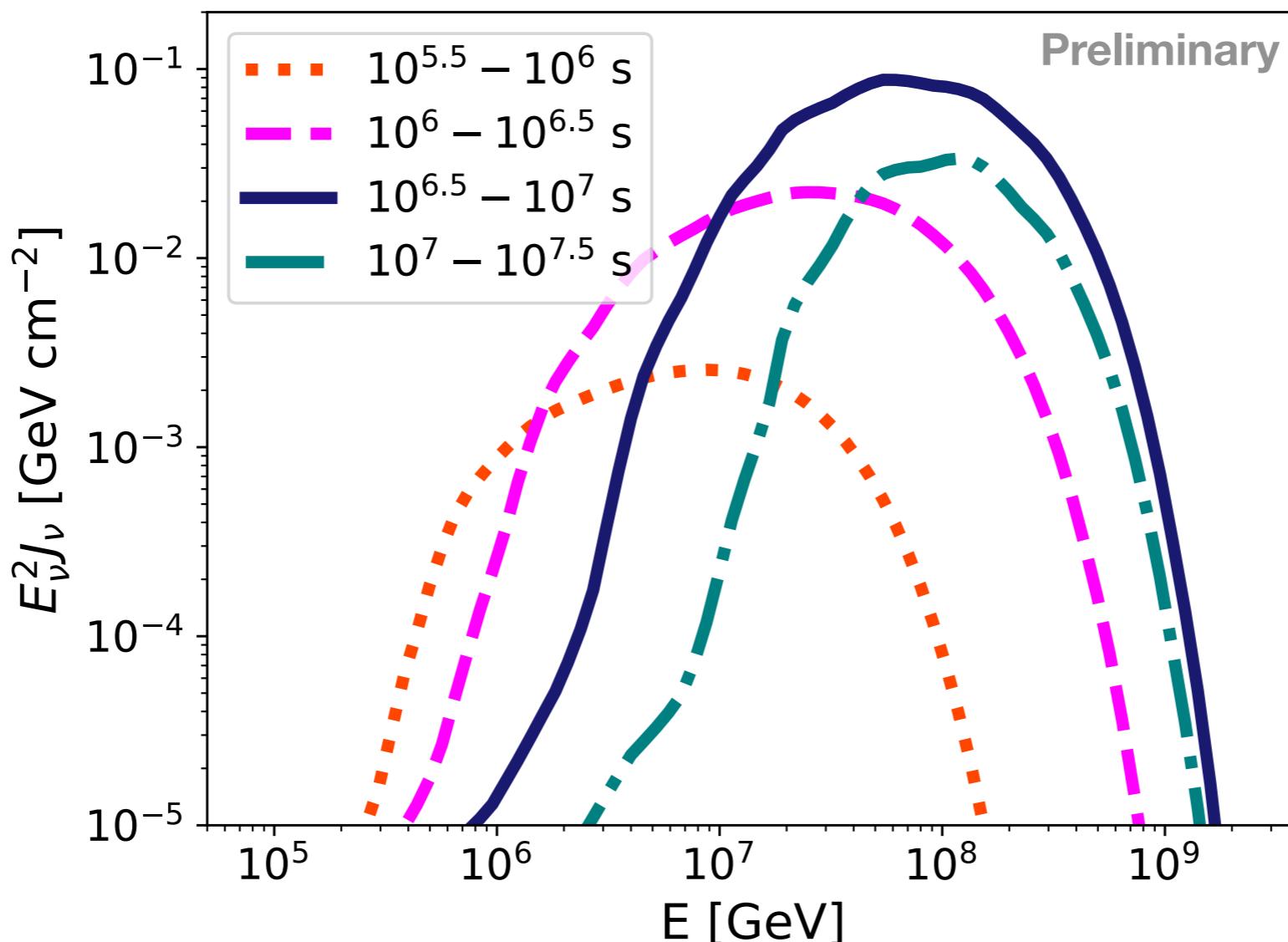
- 1) Interaction with nebular radiation:
photonuclear interactions
- 2) Interaction baryons in ejecta:
photohadronic interactions
Synchrotron cooling
- 3)

Accelerated CRs interact with baryons in the ejecta:

$$p + \gamma(p) \rightarrow p + \pi^{\pm, 0}$$

Neutrino production: needs efficient pion production (compete with synchrotron cooling)

Neutrino signatures (10 Mpc)

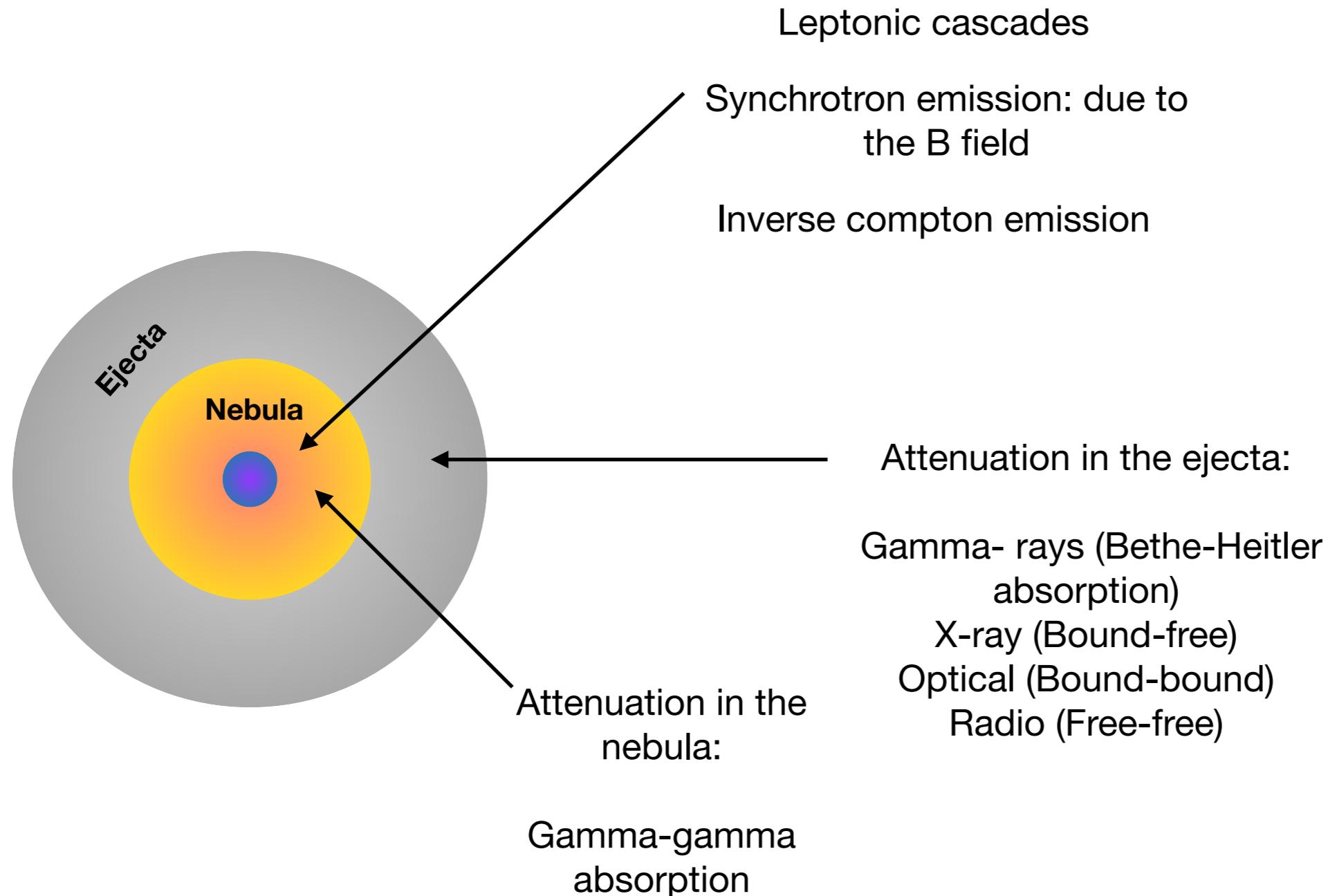


Neutrino emission timescale is \sim a few months post the merger

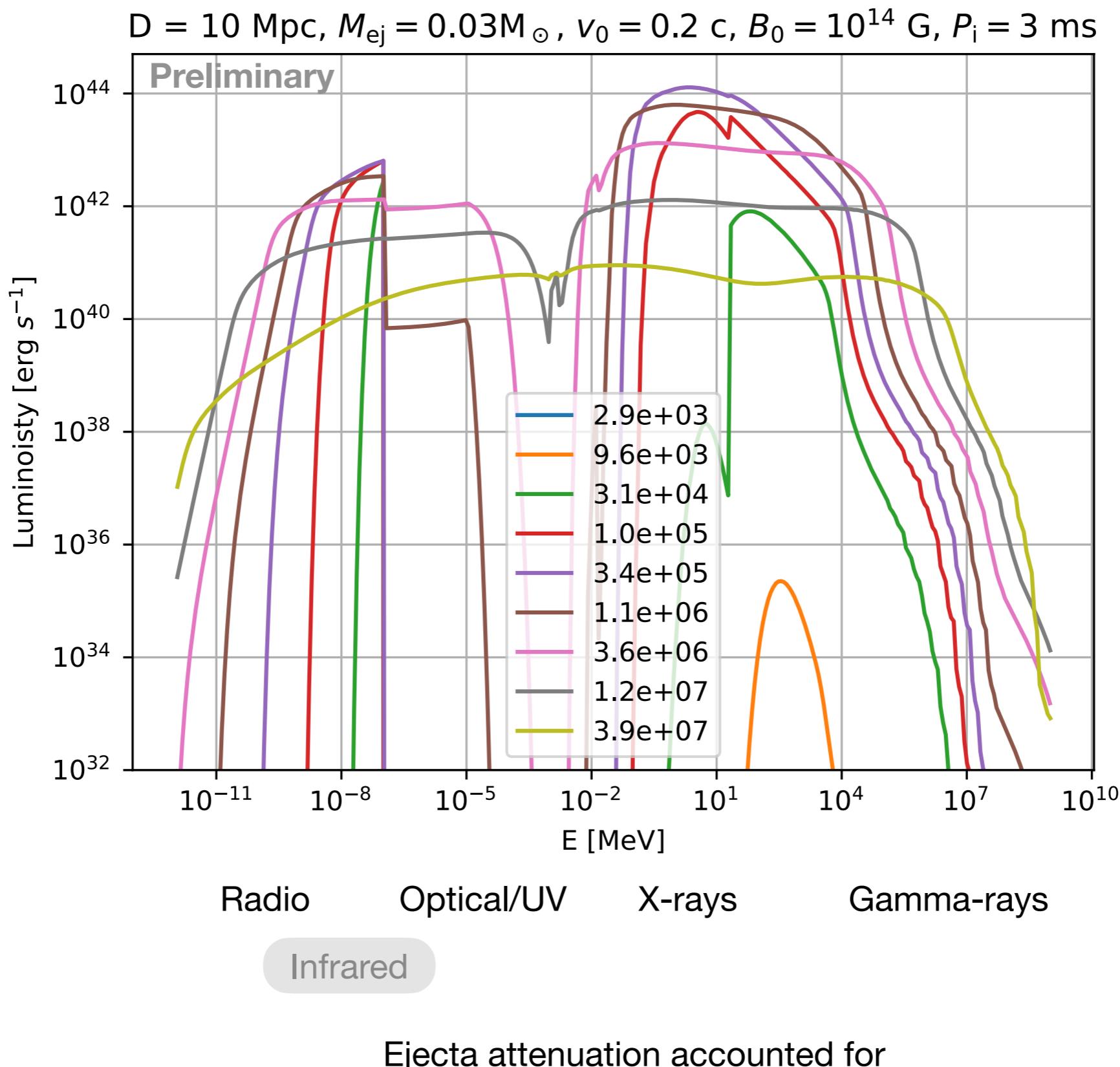
Neutrinos from a single source not detectable \rightarrow Stacking searches, gravitational wave/EM triggered searches

The diffuse neutrino flux does not violate the IceCube EHE limits

EM emissions

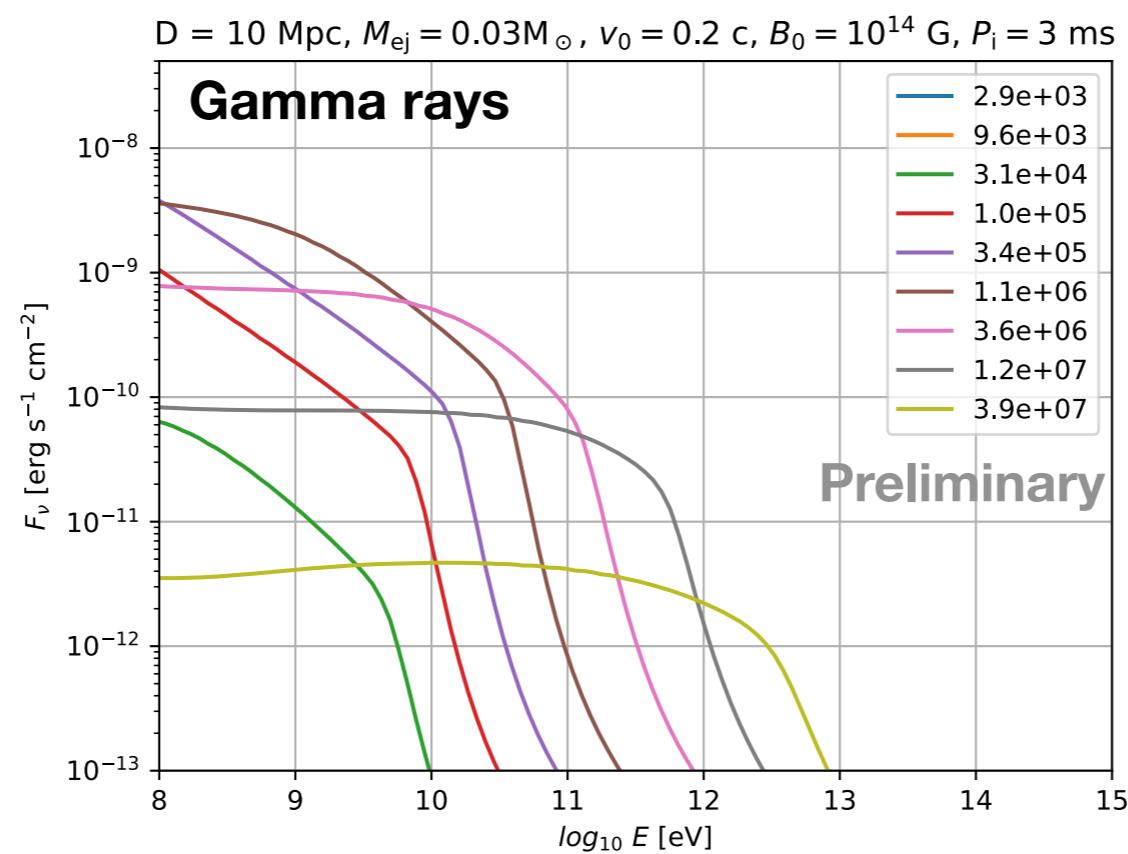
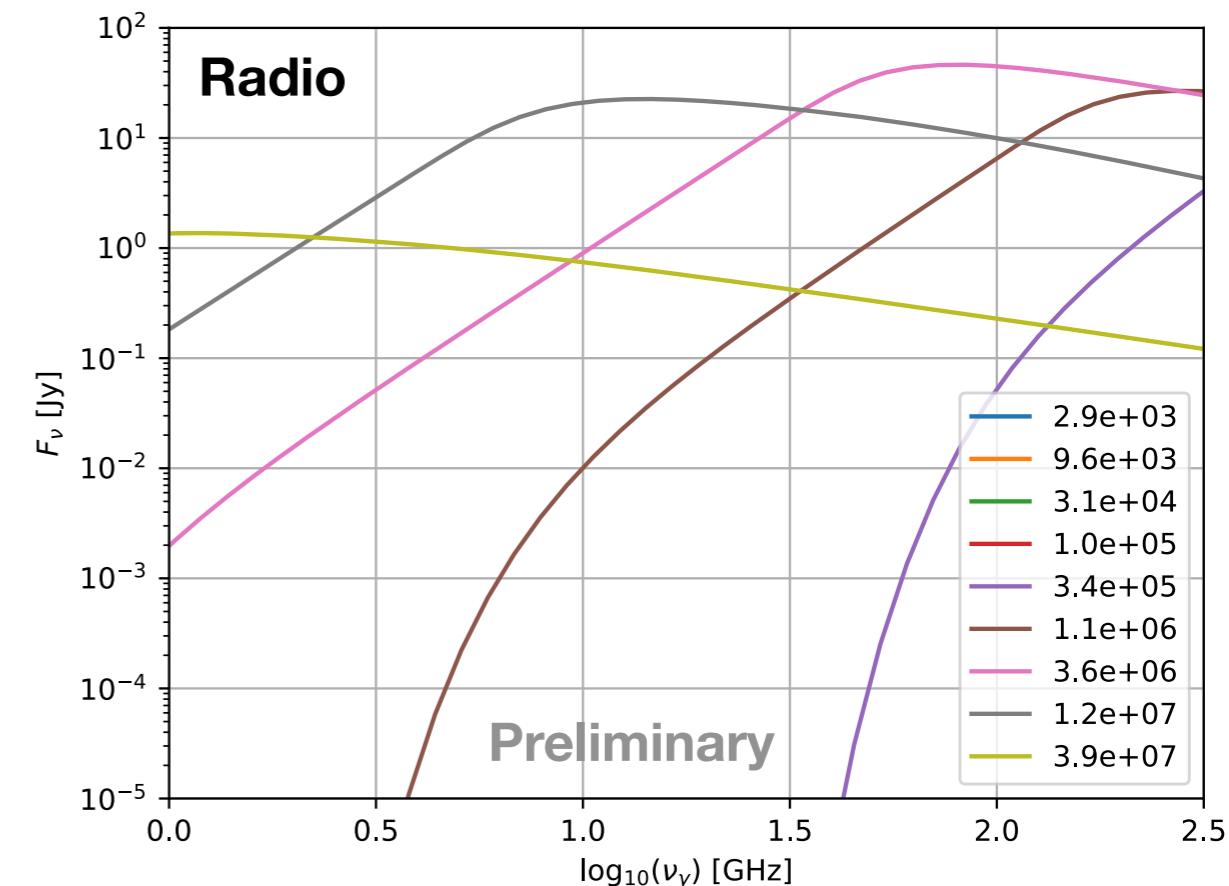
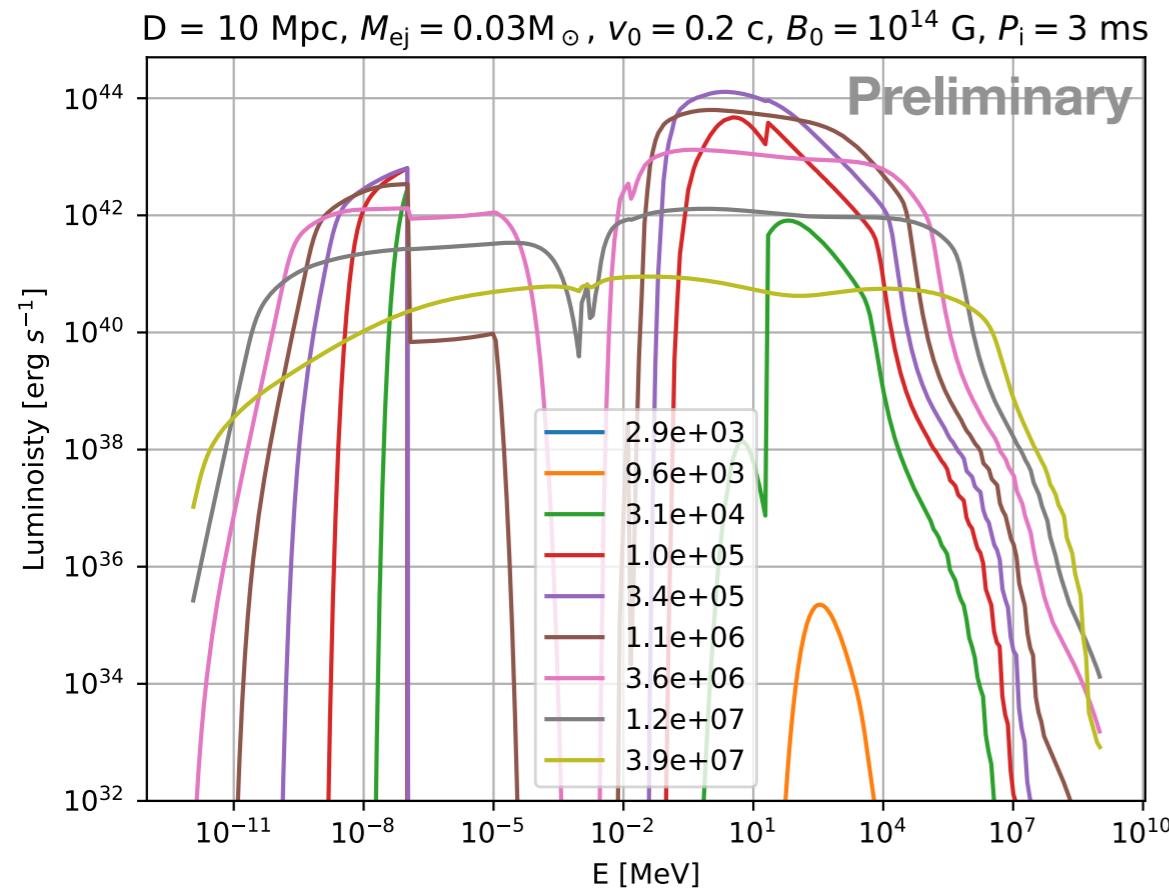


EM Signatures



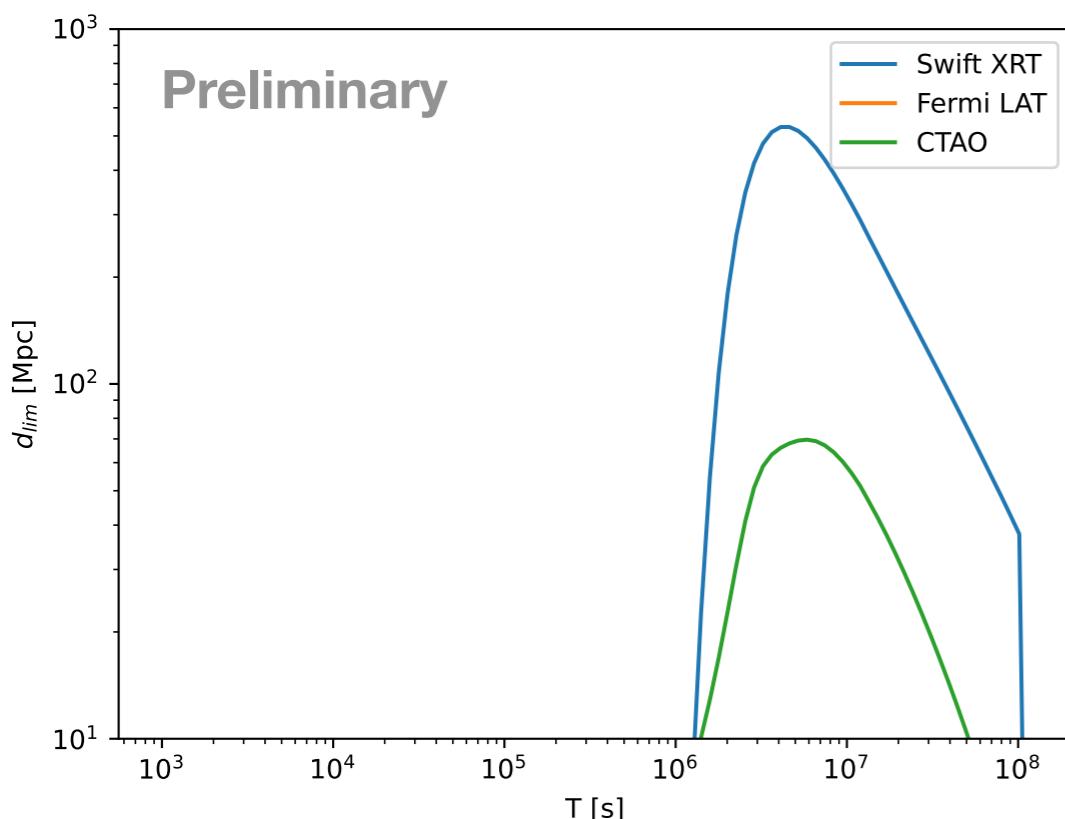
EM Signatures

$$D = 10 \text{ Mpc}, M_{\text{ej}} = 0.03M_{\odot}, v_0 = 0.2 c, B_0 = 10^{14} \text{ G}, P_i = 3 \text{ ms}$$



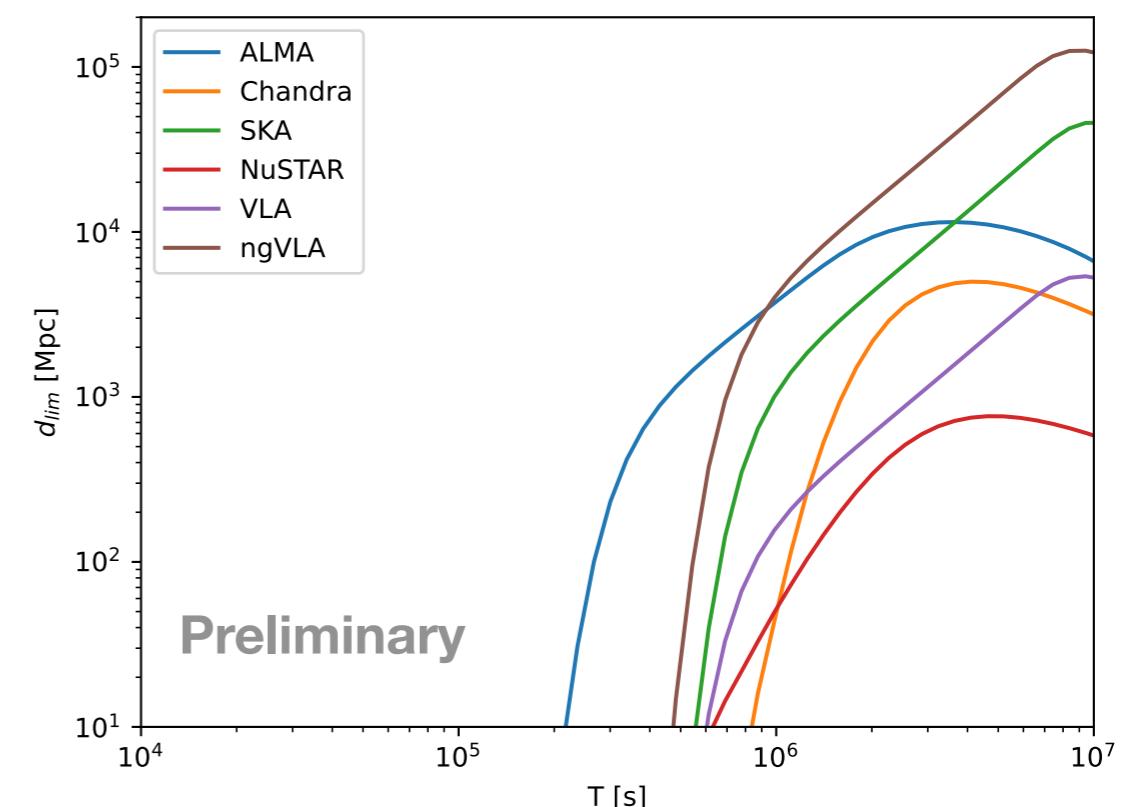
Radio light curves
peak ~ a few months
post the merger

EM Signatures: observational prospects



Survey telescopes: for discovery

Limited mostly by survey telescope distance limits



Pointing telescopes: for study

Radio telescopes:
VLA ~ 5 Gpc ~ a few months post merger
ALMA ~ 10 Gpc ~ a month post merger

X-ray telescopes:
Chandra ~ 5 Gpc ~ a month post merger

Takeaways

Magnetars from BNS mergers: multi-messenger emissions in the EM and neutrino channels

- Spin down energy -> Drives nebula -> Drives ejecta
- Highly ionized nebula -> Thermal + non-thermal photons, Ejecta -> Thermal photons + Baryons
- The spin-down energy peaks at the spin down timescale and then decreases.

Neutrino and EM signatures

- CRs are accelerated in the nebula and interact with baryons and photons in the ejecta.
- Leptonic processes -> Synchrotron, Inverse compton -> EM emissions -> attenuated by the nebula and ejecta
- Detectable unto 0.5 Gpc using survey telescopes like Swift XRT and CTAO (main limitation). Pointing telescopes: much better prospects -> sensitive to Gpc and above.
- Neutrino emissions from pp and p γ interactions: timescales ~ a few months post merger
- Stacking search necessary: GW triggered observations and EM observations improve the prospects.

Thank You!

Backup